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FROM
American Journal of Insanity,
April, 1889.
UTICA, N. Y.

THE ENCEPHALIC CIRCULATION AND ITS RELATION TO THE MIND.

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Of old, it was denied that organic changes have even coincidence with psychic manifestations; but to-day, he who would aspire to be a *connoisseur*, or even a dilettant, in matters of the mind must know something of the mechanism in which mind finds its habitat. Every one now recognizes the importance here, as elsewhere, of practical inductive studies; and just at present problems pertaining to the dynamics of the encephalon are attracting especial attention. Of salient importance, it is everywhere admitted, is the circulatory apparatus. Alienists differ in opinion as to the exact relation which it bears to the *ego*, but all concede that the blood supply is one factor in the genesis of mind; and not only so, but that it is an absolutely essential one, and the one most easily demonstrable. And this latter fact gives it a fresh charm; for the modern mind clings ever to the tangible.

It is the purpose of the present paper to give a brief outline of the conditions under which the encephalic circulation is carried on; and, while steering as far as may be from controversial rocks, to make what seem to the writer some fairly warrantable suggestions as to the connection between vascular changes and mental states, normal and abnormal. But before entering upon the subject specifically, a prefatory word seems advisable—nay necessary—to prevent a possible misconception. While the present paper will, in keeping with its heading, deal almost exclusively with vascular conditions as somatic concomitants of psychical states, I would not be understood as wishing to relegate to the circulatory apparatus exclusively the conduct of the intellect. On the contrary, I recognize fully the salient importance of the "nervous" element, as being not only antecedent to the vascular

change, but its consequent as well, and, indeed, at all times its indispensable co-worker. My intention here is merely to present the more elementary, but more often neglected, phase of the subject, leaving the complementary aspect for consideration in a subsequent paper. So intimately associated are the two, however, that we can scarcely hope to be able to rigorously confine ourselves within the bounds of our subject; but we shall not cross them oftener than seems unavoidable. We will first study the conditions under which the encephalic circulation is carried on.

These conditions, in themselves, are not greatly involved. They are, however, organically unique. Elsewhere the blood vessels are encased in soft, yielding tissues, subject directly to the atmospheric pressure. The volume of a limb may vary considerably, and its outline is constantly undergoing variations, both as to contour and environmental influences; but the skull case is fixed, unyielding and invariable. It is true that there are openings into it, to transmit soft tissues (vessels and nerves) but these are altogether inconspicuous in size, as compared with the entire area of the skull surface; and their lumen is completely filled with tissues, which, though slightly yielding, are constantly under considerable pressure; so that, for all practical purposes, we may safely disregard them, and speak of the skull as a perfectly inelastic encasement.

It need hardly be mentioned that the cavity of the spinal column forms a simple continuation of that of the skull, and that both are subject to the same conditions. In proportion to its size, the spinal canal has more openings in its bony casement than has the cranial cavity, but these are filled with very tough, inelastic, fibrous matter, and, in most positions of the body, subjected to increased pressure. It can hardly fail to be apparent, therefore, that a force sufficient to distend them, if applied to the brain, could not well be borne by the delicate cerebral tissues. Nor, indeed, could such a force be supplied by the tenuous cerebral arteries. We are thus forced to accept as one of the conditions of our problem, the practical inelasticity of the walls of the entire cavity in which lies the cerebro-spinal nervous mechanism.

Throughout the cavity, there must be a constant tendency to equalization of pressure, subject only to variations due to gravitation; and it is evident that the same fundamental physiological conditions must pertain to both encephalic and spinal circulations; but for convenience we shall confine our attention to the former.

Given our closed cranial cavity, then, what are its contents?

Generally speaking, these may be referred to as semi-solids and liquids. Free gases do not occur in the living brain, and solids are inconspicuous. The protoplasm which makes up the mass of the brain, is itself really a liquid, but a mass of fibrous tissue gives it comparative stability, and we may conveniently refer to it as the semi-solid portion of the encephalon.

The liquids present are lymph, a clear serum, and the blood; the two former being, of course, derivatives of the latter. The bulk of the brain tissue is far too inelastic to admit of absolute condensation under slight pressure; and molecular changes cannot be sufficiently rapid to essentially alter its amount momentarily. We are therefore justified in predicating comparative constancy of size of the semi-solid portion of the encephalon. From this it follows, that the absolute amount of liquid in the cranial cavity must also be a constant. If, then, there is to be a change in the aggregate amount of blood supplied to the brain, there must be a compensatory fluctuation of the complementary fluids, the serum and lymph.

Such changes undoubtedly occur, and they furnish some of the most important problems connected with cerebral dynamics. How are they to be explained? Certain old time writers said that the serum was pressed down into the spinal canal when the blood supply to the brain increased, and returned when it diminished; but it does not appear as to what they assumed to be done with the liquid which already filled this cavity. Some more recent writers have explained that the fluid of the sub-arachnoidean space is simply transferred to the ventricles when the blood increases; but they also fail to mention the disposition made of the ventricular fluid already inconveniently present. Such explanations as these, occurring in important and authoritative works, prove that the subject is widely misunderstood. The difficulty has resulted from carelessness in examining the existing physical conditions. It is only necessary to call attention to these, to prove that any absolute increase of blood supply can be explained in no other way than by supposing a corresponding diminution in the quantity of serum or of lymph present in the entire cerebro-spinal cavity. If a cubic centimetre of blood is to be added to the quantity already circulating within the cranium, a cubic centimetre of serum or lymph, must be altogether removed from the encephalon. This fact being self-evident, it remains only to explain the process by which this removal is brought about.

Only two possible channels present themselves: the lymphatic

system and the vascular. The peri-vascular and sub-arachnoidean spaces of the brain are in connection with the lymphatics of the pia; and it has been experimentally demonstrated (Golgi) that an increase in intra cranial blood pressure, hastens the flow of lymph through the thoracic duct. Some authorities (e. g., Rosenthal) suppose this change sufficient to account for all congestive conditions of the brain; but it seems to me highly improbable that even the greatest possible acceleration of the flow in these exceedingly small channels could account for the rather rapid cerebral congestion which every one admits to occur. All rapid and general hyperæmias of the encephalon—and it seems to me most minor ones, also—can best be explained by calling into account a rapid osmotic action through the tenuous walls of the encephalic arterioles and capillaries. These must absorb and sweep altogether out of the cranium a quantity of serum equal in bulk to the blood that is being added, less the (as I believe inconspicuous) portion carried off by the lymphatics. Of course at the moment when the absorption takes place the serum so taken up becomes a portion of the blood. It has simply percolated through an arterial wall, and while the vessel is dilated, its lumen contains no more corpuscles than before; but the next instant the excess of serum has been swept out of the brain, and its place is taken by corpuscle-bearing blood. In reality the process takes place somewhat gradually,—though probably far more rapidly than has usually been assumed,—but the result is as noted. But whatever may be the difference of opinion as to the relative share of lymph acceleration and direct osmosis in the congestive conditions of the brain, there is no opportunity for diversity of opinion as to what must take place when the blood supply of the brain is lessened. Since lymph and serum are both blood derivatives, it is clearly impossible for either to reach the brain except as exuded from the blood. And such exudation must take place, compensatorily, with every general arterial contraction in the brain,—that is, whenever the blood supply is lessened.

Thus and not otherwise, can be explained absolute changes in the encephalic blood supply. How beautifully adapted the structure is for such changes, a consideration of the elaborate system of peri-vascular spaces, and of the contact of the vascular pia mater with the sub-arachnoidean space (itself only a larger peri-vascular cavity) will at once make manifest. Incidentally, it may be noted how marvelously the delicate cerebral tissues are thus protected against very sudden changes in the circulation; the serum not

only cushioning the cells everywhere, but by an oscillatory osmosis tending constantly to equalize the pressure in the brain, which otherwise must vary much more suddenly with changes in the heart beat. The extreme tenuity of the cerebral vessels permits of very rapid osmosis, though it cannot be supposed that a change here is ever instantaneous. Some results of these changes will appear a little later.

It must not be supposed, however, that circulatory changes in the brain are confined to absolute increase and diminution of the blood. On the contrary, fluctuations within the cranium, between different parts of the vascular apparatus, are constantly occurring. These fluctuations are of two kinds,—arteric-venous and inter-arterial. In the brain, as elsewhere, the veins are merely passive return channels; and the sinuses are, in effect, only larger veins. Gowers has called attention to the anomalous course of the veins in the encephalon, by reason of which the current of blood is in most positions of the body, upward through the veins to the sinuses, over almost the entire cortical surface. The equilibration of forces in the skull, however, and the fact that gravitation makes the pressure greatest at the base of the brain, may help to overcome this seeming disadvantage.

Arterio-venous fluctuations have been chiefly thought of in connection with pathological conditions, but it can scarcely be doubted that they operate efficiently and constantly in physiological states. For example, an increased arterial pressure may tend to dilate the cerebral arteries at a time when conditions are not favorable to absorption of the peri-vascular fluid, or more rapidly that such absorption can occur. In such a case, the increased intra-cranial pressure must hasten the flow of venous blood, (aside from the increase of the *vis a tergo*, be it understood), by compressing the veins in a measure, thus permitting arterial dilatation independent of peri-vascular absorption. To a certain extent this must always occur under such conditions, and the more rapid general changes in arterial capacity are doubtless thus explicable; but it will be noted, of course, that the absolute quantity of blood, arterial and venous, in the encephalon, is not thereby altered. Conversely, sudden contractions of the arterioles may tend to decrease the general extra-vascular pressure in the brain, hastening at the same time the capillary circulation, and dilating and flooding the veins; the entire process being simply the reverse of the one just noted. In diseased states, either condition may be somewhat permanent. A passive (venous) congestion, indeed, may cause a true arterial anæmia, while yet

there is sufficient blood in the brain. The opposite condition—that of venous deficiency—might co-exist with arterial hyperæmia, but only in case of a static form of congestion. In ordinary hyperæmia, the turgid arterial channels demand full venous outlet, and the peri-vascular spaces and the lymph channels are probably infringed upon, rather than the veins. Constant variations of this arterio-venous interplay are unquestionably occurring in the normal brain; and exaggerated changes of the same nature, in abnormal states.

Supplementing the three methods of variation just referred to, and always more or less intimately associated with them, is the fourth method of change,—the inter-arterial fluctuation. Probably all these methods of variation are usually in operation together in any given portion of the brain, one or another predominating. Bearing this in mind we will briefly consider this inter-arterial oscillation by itself, as we have done with each of the others. It is made possible by the anatomical arrangement of the cerebral vessels. These, as is well known, are terminal,—that is, each artery has its own set of capillaries and veins, and does not anastomose freely with other systems. If an embolus fills the lumen of the posterior cerebral artery, for example, a tolerably distinct area of degeneration occurs in the occipital and temporo-sphenoidal lobes. In most other tissues of the body, anastomosing arteries would soon supply the deficiency; but not so here. And in lesser twigs it is the same, even to the little looplets each one of which supplies only a microscopic area of the cortex. This isolation however, is not absolute, and it varies in degree in different brains,—variations, as will be noted later, that may explain some differences in the workings of divers minds.

Let us see now, tangibly, what results from this terminal arrangement. Suppose that the cortical area, supplied by the anterior cerebral artery has been in active operation and correspondingly hyperæmic, but that it becomes desirable to utilize the area supplied by the middle cerebral instead; while at the same time, no general change in the amount of blood supplied is feasible. It will be readily seen that an arterial vaso-governing apparatus might concomitantly contract the anterior cerebral and dilate the middle cerebral, the latter thus receiving the surplus blood that is shut out from the former, while the aggregate amount of blood supplied to the two remains unchanged, as also the peri-vascular fluid, provided only that the tissues between the two arteries were sufficiently plastic to admit of the necessary displacement. That

such is really the case, a consideration of the plasticity of the tissue making up the brain, leaves no occasion to doubt.

While, to make the illustration clear, we have utilized two of the larger arteries of the brain, it is plain that lesser twigs will much more frequently be called into requisition; indeed, we may reasonably suppose that inter-arterial fluctuations between the twiglets of the cortex are constantly occurring, coincidently with the shifting currents of thought which they help to evolve. Such intimate changes, more particularly called into requisition in connection with the glimmering oscillations of constant thought, involving the cells of a particular area of the cortex—in all parts of which circumscribed area there is intense hyperæmia and, for the time being, almost complete obliteration of the peri-vascular spaces—may be supposed to take place much more rapidly than can occur the general changes dependent upon osmosis. Yet even here, instantaneous changes are not to be admitted; and "flashes of thought" must be explained with the aid of molecular dynamics.

The four processes above considered—vasculo-lymphatic, arterio-serous, arterio-venous, and inter-arterial fluctuations—afford a synoptical view of the possible methods of change in the encephalic circulation. We have next to inquire as to the means by which changes in the circulation are brought about. The importance of these changes being admitted, it seems highly probable that some central mechanism has charge of the co-ordination of the encephalic vascular apparatus. Naturally, we look to the vaso-motor nerves for a chief share in this co-ordination. Indeed, we can think of no active arterial contraction in which the vaso-motor ganglia are not involved. Centres of vaso-constriction lie in the cervical sympathetic ganglia. Another centre lies in the medulla, and perhaps still others in the cerebral cortex. I have heretofore expressed my belief that the medullary centre is vaso-inhibitory rather than vaso-motor. Morphological consistency demands that the cortical centre be considered inhibitory of the medullary centre; but this theoretical consideration is as yet neither justified nor discountenanced by observed phenomena. It becomes an important question, however, as to just how much we shall attribute to these centres. Their response to certain abdominal impulses is undoubted. It may reasonably enough be assumed that they respond also (and this may be their chief function) to impulses from the brain itself; as, for example, when that organ is in need of rest. But the important thing to be noted in connection with either kind of action, is that it is always purely reflex, that is to say, it

is in response to an impulse from without the centre; and, further, that it is an unconscious reflex, entirely outside the power of direct volitional control. These centres, then, which govern one of the most important processes of the entire organism—a process having to do not with physical things alone but with the evolution of mind itself,—centres of such transcendent importance as these are purely automatic in their action. To those who have learned to look upon every mental manifestation as a true reflex, this will seem only the natural order of things; to others it should prove a significant and suggestive observation.

But these central stations of vaso-control can hardly be thought of as acting with any great degree of localized discrimination. Their location precludes the belief that they should be able to manage the entire affairs of so complex a mechanism as the cerebral vascular apparatus. The intricate and delicate oscillations of blood now here, now there, changing at times perhaps over microscopic areas, yet potent in results, we cannot well believe to be governed altogether by a few sympathetic ganglia, nor yet by the medullary centre. Where then shall we look for their seat of control? Surely not elsewhere than in the walls of the vessels themselves, and in their intrinsic ganglia. Just as the ganglia of the heart influence the action of that organ, so the entirely comparable ganglia of the arterial walls must act, each on its own particular set of fibres, to control the local changes in the arterioles. The stimulus to action here must lie, not in the arteries themselves so much as in the chemism of the protoplasm about them,—the innervating of the cells which are the essential cerebral elements. A consideration of the exact nature and effect of this innervation belongs to the subject of molecular dynamics, and will be taken up at another time. Suffice it here, that it is quite as conspicuously reflex as is the arterial contraction itself.

So much for the arterial changes directly due to nervous action of the controlling ganglia, extrinsic and intrinsic. All changes actively involving the vascular apparatus must begin with these ganglia, or be reflected through them; but there are numerous ulterior influences that are important as complicating their action. The most prominent of these are dependent upon the heart. A weak or insufficient heart may by altering the cerebral circulation, change what would otherwise be a powerful mind to one of lassitude and inapplication. Contrariwise, a powerful heart tends to give the brain opportunity to innervate with its utmost vigor. The authors, whoever they may have been, of the figurative

expressions "strong of heart" and "faint hearted," as descriptive of opposite mental traits, expressed probably far better than they knew, a casual relation between the physical and the mental. It is probably not going too far to assert that a fairly good heart is essential to anything like normal cerebral circulation; and it certainly is reasonably predicable that an equable condition of the circulation is absolutely necessary to the best mental action. A too weak heart sends insufficient blood to the brain, and the result is either venous stasis and congestion or serous exudation; and in either case, imperfect innervating of the cortex. A too strong heart, on the other hand, while less markedly disadvantageous, may send an excess of blood and cause an exhaustive over-action. But between the strictly normal heart and the cerebral circulation, an equally close and intimate relation exists. So far as we know, all arterial dilatation is passive; that is, due to pressure from within. The calibre of a cerebral vessel is determined by the point of equilibrium between the general brain pressure plus the tone of the artery itself, acting in one direction; and the blood pressure within, acting in the opposite direction. Both of these are varying factors. The arterial tone, changing with the ganglionic innervation, we have already considered. The internal tension undoubtedly depends upon the general blood pressure without the cranium; and this, of course, largely upon the heart. Any increased action of the heart, therefore, tends to dilate the cerebral vessels. We have already seen that the pressure outside of the cerebral vessels prevents anything like the free and rapid dilatation that occurs in the systemic arteries at large. But we have also noted that a slight oscillation is presumably always in operation; and it is exceedingly probable that violent action of the heart may at times result in positive hyperæmia of the brain. A constant interchange of forces thus is taking place between the heart and the cerebral vessels, and it is superlatively interesting to consider the beautiful mechanism by which the same ganglionic and medullary centres preside over both, admitting thus of a marvelous co-ordination. The same impulse thus, which, coming from the cervical ganglia, accelerates the heart beat, may stimulate a contraction of the cerebral vessels to meet the shock; and a medullary impulse, inhibiting the cardiac action, inhibits also, through the cervical ganglia, the power of the cerebral vessels; thus as before, maintaining that equilibrium which is an essential concomitant of equable thought. Thus here, as so often elsewhere in the animal body, is seen, a beautiful reciprocal adjustment,—of

which indeed the organism as a whole is merely a greater manifestation.

Another influence having a not unimportant bearing upon the cerebral circulation is that resulting from changes in bodily position. This, however, is not as conspicuous as might at first thought appear, because of the comparative fixity insured by the unique conditions already discussed. Were the brain surrounded only by yielding tissues, the greatest and most studied care would be necessary in all our motions, lest there be produced so marked a change in the cerebral circulation as to seriously injure the encephalic tissue. An amount of vascular alteration equal to that which occurs in the hand whenever that member is simply dropped to the side after resting horizontally, would, if it occurred in the brain, produce the most profound mental aberration, or an absolute obliteration of consciousness. But no such marked change occurs with slight or temporary alterations of the position of the cephalon. True, a man inverted could not think well; but it is questionable whether the discomfort that results from lowering the head does not originate more in the superficial vessels of the face than in the vessels within the skull. At any rate, between the horizontal and erect postures, there is no such conspicuous change in the encephalic circulation as there is in the hand or foot. But while these observations go to show that momentary changes in position are comparatively without effect upon the cerebral circulation, it is none the less true that positions of the body are gradually effectual in producing changes here as elsewhere. A consideration of some of these affords interesting clues to certain normal attitudes. For example, it is undoubtedly true that meditation —calm, unimpassioned thought—is best carried on while the head is inclined forward. Now such an inclination of the head must, as a moment's consideration will prove to any anatomist, relax the longitudinal tension of the carotids (and indirectly their lateral tension also) thus permitting a more equable flow of blood into the cerebral vessels. On the other hand, proud, haughty feelings accompany elevated positions of the head; positions necessitating increased carotid tension and a more impulsive circulation. And so of other states. Now it would be absurd to think that the effect of these changes is sufficient in itself to produce the mental change from meditation to haughtiness,—the fact that the positions may be used interchangeably would sufficiently disprove such a supposition,—but it cannot be questioned that in the long process of evolution, these conditions may have been efficient in

bringing about and stamping upon the race the attitudes which we now recognize as in a measure indicative of certain mental states, such as those just mentioned.

But the effect of mere changes of the head itself are at most but slight; and probably more depends upon the position of other members,—as, for example the lower extremities. Many persons with rather feeble hearts find that they can think best when the lower limbs are slightly elevated or placed horizontally. The aid thus given the heart by gravitation is very considerable and must indubitably affect the brain also. Probably thus rather than through direct influence upon the cerebral arteries, is to be explained the fact, if fact it be, that some feeble persons think best in the recumbent position. There are people, again, who think best while walking; and in this connection the aid thus given to circulation, through muscular contraction must not be overlooked, though we shall find another explanation possible for this habit later on. The effect of rapid exercise in producing so turbulent a blood current as to preclude the possibility of equable thought, needs only to be referred to, finding manifest corroborations in universal experience.

Other subordinate but not inconsequential influences are brought to bear upon the cerebral circulation indirectly through changes in the digestive apparatus. During digestion the cœliac system is of course greatly dilated, and such dilatation results in a decrease of pressure at the aortic opening of carotid and innominate arteries, thus reducing the rapidity of circulation in the brain. It does not follow here of necessity that the amount of blood in the brain at any given instant is reduced; but the aggregate amount that passes through it in a given time is much lessened. Such a condition is made possible by the intimate connection of the splanchnic and cerebral circulation; the impulses that relax the cœliac vessels relaxing the cerebrals also, and thus decreasing the entire pressure in the brain without necessitating arterial constriction. If this central influence is not efficient, however, the pressure being lessened in the arteries and the tone of the arterial walls remaining unchanged, the cerebral vessels must contract and receive less blood. In either case the amount of oxygen that comes to the brain is reduced; and in the latter case the supply of serum pabulum is greatly increased. Hence there is a tendency to sleep after eating,—a tendency that becomes almost irresistible when food has been taken to the extent of satiety. This drowsiness, however, must be at least in part explained by the presence in the

blood during digestion of an excess of the nitrogenous food pabulum, encouraging constructive metabolism in the brain cells; in contradistinction to the destructive metamorphosis set up by the oxygen, and which latter alone has a distinctly conscious mental equivalent.

Variations in external temperature, altering the size of the peripheral vessels, must indirectly affect the cerebral circulation in a way too manifest to require elucidation. Prolonged exposure to extremes of temperature produces conspicuous mental effects; but while it does so in a measure through the circulatory apparatus, there is introduced also a nervous element that cannot be considered here.

Without further elaboration of the conditions effecting the cerebral circulation, those already instanced sufficiently illustrate the exceedingly varied and complex character of the influences under which cerebral actions are carried on, and evidence perspicuously the necessity for that unique cranial apparatus by means of which comparative stability and equability of the encephalic circulation are made possible. Such equability, moreover, is absolutely essential to the functioning of these exquisitely sensitive tissues. Elsewhere, marked temporary changes of circulation are productive of only trifling ill effects. Compress a brachial or femoral artery so as to completely stop the circulation in the corresponding member; or apply an Esmarch's bandage, almost completely depleting the tissues for a minute or an hour; and there is no permanent ill effect. But compress the carotids for a second—consciousness is gone: continue the pressure for a minute—life itself is extinct. Such a tissue as that may well be jealously guarded. Jealously guarded indeed it is, as we have seen; and equally well is its circulatory supply provided for. Indeed its vascular supply is out of all proportion to its size,—though quite in keeping with its functional importance in the organism. The average brain represents only about two per cent of the body weight, yet it receives about ten per cent of the blood, or five times its *pro rata* share, so to speak; that is to say, while each pound of the other tissues of the body, on an average, transmits about one and a half ounces of blood, while the entire bulk of blood is passing once through the heart; each pound of brain tissue receives an amount of blood equal to half its own weight. In other words, about one and a half pounds of blood pass through the brain during a single complete circuit. But this disproportion is rendered still more striking if we remember that in the brain itself the blood is not evenly distributed, the gray cor-

tical matter being far more vascular than the remainder of the cerebral substance. If those estimates which make the cortical supply ten times that of the centrum be even approximately correct, it is evident that the amount of blood supplied the most active part of the brain is relatively enormous,—so immensely out of proportion, indeed, to that supplied any other tissue, that I hesitate to make a computation, lest it seem absurd. But though we desist from this particular line of calculation, another startling computation is necessary, in order that we may get clearly in mind the striking anomalies of the cerebral circulation. We have estimated that during a complete circuit of the blood, the brain receives about twenty-four ounces. But the average capacity of the encephalic vessels is said to be only about four ounces*; therefore the blood must pass through them at about six times its average rate of speed. This is supposing an equal distribution throughout the encephalon; but as regards the restricted area of the cortex, we will merely suggest an enormous acceleration and, as before, desist from computation. These startling intrinsic circulatory anomalies sufficiently prove—were further proof needed—the importance of the blood supply to the functionings of the central nervous apparatus; and at the same time they furnish, perhaps more perspicuously than could otherwise be done, evidence as to the marvelous play of forces that is going on in the encephalon,—the tremendous energizing, and the exceedingly rapid organic metabolisms which accompany mental manifestations. Not for one moment can that sweeping current of fiery blood be spared with safety to the organism; and it is well that the forces which control that circulation are placed far beyond reach of a capricious consciousness.

Having now seen something of the conditions under which the encephalic circulation is carried on, and having gotten an idea of the importance of this circulation, we have next to inquire as to the means of investigation that may be used in gaining an insight into the true relation between such changes and various mental states. The encephalic vessels being securely hidden from direct observation, it has been necessary to press into service all possible means of observation in order to arrive at reasonably certain inferences,—for at best our knowledge here is largely inferential. As some of these means of observation are constantly being utilized in actual practice by every physician, it may not be amiss to glance at them

* I accept this estimate on authority. The other computations are based exclusively upon measurements and estimates of my own.

here with especial reference to the value of the data they afford and hence, incidentally, to their reliability as aids to diagnosis.

One of the commonest observations,—and one let it be noted, that furnishes in itself the basis for a whole series of deductions—may be made at any time on the head of an infant; in which the fontanelles may be seen to be depressed during sleep and elevated during waking hours, becoming especially prominent during violent emotional states. These observations are perfectly unequivocal and demonstrative as far as they go; and they need no further comment here.

In the adult, very few methods of observation are so satisfactory. One of the commonest criteria of which cognizance is taken clinically is the condition of the pupils. The radiating fibres of the irides being supplied by the sympathetic nerve, it is assumed, with some reason, that a dilated pupil must coincide with arterial contraction in the brain, and *vice versa*. Notwithstanding certain theoretical considerations that favor this view, it must be insisted that the symptom is by no means universally reliable. External conditions operate so constantly upon the normal pupil that its fluctuations cannot be at all relied upon as indicative of transitory conditions in the brain. But with conspicuous aberrations of long standing and of central (sympathetic) origin, the pupil is apt to coincide. That persistent anæmia of the brain accompanying certain forms of melancholia, for example, is pretty constantly associated with a tolerably fixed and relatively immobile dilatation of the pupils, is reasonably established. Witness also the contracted pupil of paresis.

Another set of symptoms very widely accredited with diagnostic value, has reference to the vascular supply of the face. The vessels here being supplied with vaso-motor nerves from the same source as the encephalon (*i. e.*, from the cervical sympathetic), it would naturally be assumed that the circulations in the two must be parallel. But experiment has demonstrated that sometimes a single stimulus supplied to the cerebral sympathetic will produce opposite effects upon the facial arteries and those supplied to the ear (and brain also, presumably); and the conclusion based upon this observation is abundantly upheld by other considerations. The facts seem to be that the two circulations, facial and encephalic, do often—perhaps usually—coincide in a measure; but that they are at other times complementary. And the two conditions are fairly well differentiated ætiologically. When the impulses causing a change in the cerebral circulation comes as the reflex of a cerebral appeal, or as a direct stimulus from the vaso-controlling

centres, the effect is quite likely to be confined to the brain itself, and the facial circulation may be compensatorily altered in the opposite direction. For example, if we notice a student undertaking some difficult problem in a composed and equable but concentrated way, we shall find that his face becomes pale; yet it cannot be doubted that at the same time his brain is hyperæmic, at least in portions of its cortex. A person who becomes white with anger affords another illustration of the same kind. That anger is often accompanied by flushing of the face, is because the heart usually begins to beat tumultuously; and this is especially true when anger is accompanied by active muscular exertion, aggressive or defensive; in which case the face which was blanched while the rage was suppressed becomes almost instantly turgid.

But on the other hand, circulatory changes due to more general causes, such as constitutional dyscrasiæ, changes in heart beat, and any other causes affecting the pressure at the carotid openings, naturally affect both facial and cerebral circulations in like manner. Thus a general plethora is manifested by a flushed face and an equally flushed brain (witness here the tendency to cerebral hæmorrhage); and a persistent anæmia of the body is almost certain to be accompanied by an anæmic brain, as well as by a pale face. Of more transitory conditions in which there is coincidence, the flushed excited anger, already instanced, is an illustration, and there may in addition be cited: terror, which operates in exactly the opposite manner, primarily by blanching brain, but then by blanching the face also, through an inhibitory effect on the heart's action; the general cephalic flushes that results from vigorous exercise, in which the face also is flushed; and in general, as already intimated, nearly all conditions that operate primarily through the blood current rather than through the nervous mechanism. The diagnostic importance of this ætiological distinction cannot be too strongly insisted upon.

Another avenue of observation giving certain clues to the cerebral circulation is afforded by the eyes. Time out of mind the eyes have been referred to as the windows of the soul; but modern ophthalmoscopy has taken this concept from the domain of poetry by rendering the eyes literal windows, if not to soul, at least to brain and the blood currents that move within it. But we must not expect too much from the ophthalmoscope in this capacity, for at best it must be remembered, the retinæ are only outer corridors of the mind-storing mechanism, not portions of the main structure itself. Furthermore our technique in the manipulation of the

instrument is by no means perfect; and it is doubted by the best ophthalmologists whether we can by examination of the retina make out a simple congestion of that tissue. To minor and transitory changes in the cerebral circulation, it thus affords no clue. But chronic degenerative changes, inflammations and gross lesions in the brain often leave a record in the retina; and these records are of great diagnostic importance. In attempting to draw conclusions from mere vascular conditions of the retina, however, it should not be overlooked that the mydriatics often necessarily called into requisition, may affect the condition of the retinal circulation.

Other sources of information as to the condition of the cerebral circulation, which need only be mentioned here, are observations of the carotid pulse; and the still more indirect inferences from objective study of the effects of drugs having vasomotor influence on the organism. But the latter must be used very guardedly, and only as corroborative evidence; for we know little of any drug having a specific localized effect upon the cerebral vessels alone. Most drugs that effect the cerebral circulation at all, act so markedly on the splanchnic system also as to greatly vitiate the evidence otherwise derivable from their effects. Of those producing somewhat unequivocal symptoms, alcohol is perhaps the most conspicuous.

But after all other methods of investigation have been exhausted, often with a meagre and unsatisfactory result, we are sometimes permitted, as a last resort, to turn to that tribunal to which the pathologist must so often refer as the court of final appeal,—a post mortem examination. It is contended by some excellent authorities, however, that even here we have no possibility of securing unequivocal data; such persons maintaining that post mortem changes markedly alter the vascular condition of the encephalic tissues. My own observations however, extending over a considerable number of cases (including the careful study of the brains of about one hundred and fifty insane subjects, in which vascular aberrations are almost always conspicuous,) lead me to place great confidence in the post mortem appearances of the encephalon, even though the examination be not made for several hours after death. Theoretical considerations, furthermore, seem to me to warrant such a position. The encephalon lies in a closed cavity no less after death than before. Anything that is taken from it must therefore be replaced by an equal bulk of matter. Obviously the

circulatory apparatus affords the only channel for alteration. At the moment when the heart stops beating, the blood probably becomes almost static in the brain. A slight further propulsion into the capillaries and veins of arterial blood doubtless occurs; but it is equally certain that it is only a slight displacement, for nothing is more common than to find even the largest cerebral arteries filled with blood when examined post mortem. Of course all circulation of the blood anywhere is only a manifestation of an attempt at equilibrium of pressure; and the amount of change that occurs after death merely represents the difference in pressure existing between arteries and veins. In the body at large, such is the superior elasticity and contractile power of the arteries that they empty themselves almost entirely after death, driving the blood into the capillaries and the veins. But in the closed skull the conditions much more closely approximate equilibrium, and the veins, even if only partially full, are not readily distensible, owing to the pressure about them. Equilibrium therefore usually results while the arteries are at least approximately as in life. But the question now becomes: Are these conditions permanent? Some authorities maintain not; but a theoretical consideration of the subject may help us to a decision, since observers differ. In the first place, nothing can get out of the skull except by the vascular channels. No changes occur in these elsewhere in the body, except a general settling of the blood, from the time when equilibrium is established until decomposition sets in. When this occurs, it is supposable that gases may form and force a portion of the blood out of the sinuses or veins, if it be not coagulated; but this will hardly take place until general post mortem changes have occurred to such an extent as to make all observations unreliable. As regards settling of blood in the encephalon, it is evident that the isolation of the arteries in terminal loops precludes the possibility of anything like the general hypostasis that occurs elsewhere in the body, even were the cavity not a closed one. Theoretically, then, we would expect to find for several hours after death (and until decomposition sets in) a condition of the encephalic vessels fairly representative of their ante-mortem condition. And practically, in my own opinion, this is exactly what we do find in the great majority of instances. Indeed, in cases of acute insanity, where the symptoms during life have been characteristic and marked, it is possible to predict with much confidence the condition that an autopsy will reveal. And such observations, checking unequivocally the symptoms noted

during life, furnish the final test which converts our otherwise doubtful inference into a reasonably definite and certain element of scientific knowledge.

We turn now to the obverse aspect of the phenomena that have been briefly discussed,—to a consideration of the mental equivalents of changes in the encephalic circulation. Throughout the preceding pages, indeed, there have been repeated tacit assumptions as to the general effects of alterations in the blood supply; but these have been introduced unavoidably and with no specific intent. Now, however, we shall make a practical application of the data already gathered; or rather shall attempt to correlate these with the subjective data furnished by psychological studies. In considering the mental concomitants of vascular fluctuations, no attempt will here be made to go back of the coincidence immediately involved; an attempt at closer analysis being postponed till we have studied into the molecular dynamics of the encephalic tissues, when we shall hope to return to a fuller discussion of the conditions here outlined, and to a more comprehensive study of the physical processes underlying abnormal mental states.

Changes in circulation affect the tissues chemically in two distinct ways: they alter the recuperative process by changing the amount of food supplied to the brain tissues; and they alter the destructive metamorphoses by bringing more or less oxygen to the encephalic cells. These processes may be said to be of equal importance, inasmuch as each is absolutely essential to the life of the organism; but variations in oxygenation produce the most striking results, since consciousness is the direct accompaniment of the destructive metamorphoses of the brain cell, while the constructive metabolism is carried on independently of the *ego*,—being indeed the time for sleeping of the individual cell. This unconscious recuperative process is at all times going on in some portions of the cortex, and could it be made to balance the destructive process momentarily, there would be no necessity for the time of general cortical rest known as sleep. But the oxygenation goes on with such extreme rapidity during waking hours that an organic necessity arises from time to time for a partial withdrawal of the oxygen, that the recuperative process may be made to balance the destructive, or to approximately balance it (exceeding it by a little during adolescence, and lacking a little of equalling it during senescence). Here again we are making an assumption as to the specific effect of the increase in circulation on the cerebral tissues. Once for all, it may

be said that all methods of investigation unite to prove, what might have been maintained *a priori* as a biological axiom independent of proof, —namely, that increase of oxygen-bearing blood accompanies increase of destructive metamorphoses of the cerebral tissues; and decrease of the oxygen supply is accompanied by increase of serum, bearing the nitrogenous products that enter into the constructive metamorphosis of the tissues. And since the destructive metamorphosis finds its mental equivalent in conscious states, this assertion is equivalent to saying that the amount of blood supplied the encephalon bears a direct relation to the extent and intensity of the manifestation of mentality,—to what might be styled the momentum of the *ego*. By which it is implied that consciousness is not a single equable status of the organism; neither is it so, any more than sleep or life itself. But of this more at another time. Meanwhile if we do not forget these base lines, we shall scarcely go astray in the concise correlations of physical phenomena to mental states which are about to be suggested.

But aside from the chemical effects wrought by the circulation there is the purely mechanical effect of intra-cranial pressure constantly in operation and constantly varying with alteration of the blood supply; and this must be of salient importance in its influence upon intellection, inasmuch as very decided changes produce the most startling alterations to which the mind is subject,—nothing less than an obliteration of consciousness itself. This result, moreover, is produced either by a great increase or a great decrease of intra-cranial pressure. At first sight, this seeming similarity of the effects of opposite causes appears paradoxical, and might lead to a question as to the validity of our symptomatological knowledge as bearing upon conditions of the brain.

But it must be remembered that extreme changes in environmental forces everywhere effect the organism in seemingly identical manner when carried to the extent of absolute noxiousness. For example, extreme application of heat and the extreme withdrawal of heat from the tissues produce symptoms that are scarcely to be discriminated; yet heat and cold when applied within physiological limits are productive of very different conditions. And so of pressure in the cranium: moderate increase or decrease producing characteristic mental symptoms extreme increase or decrease resulting in opposite abnormal states of such intensity that, in one direction or the other as the case may be, the border lines of consciousness are crossed. The specific effects of changes

of pressure within these limits will be considered in a subsequent paper. The present suggestions will take cognizance only of the general results of vascular fluctuations, without very specifically outlining the portions of the result due to pressure and those due to changes in oxygenation or nitrization of the tissues,—three influences that act always in unison in the encephalon.

For the purposes of this brief synopsis we shall perhaps do best to follow somewhat the same order that we took up in considering the anatomical classes of possible change. Of course true isolation is not possible anywhere in psychology, all classifications being arbitrary; but for purposes of analysis and explanation we may speak of the mental processes as isolated, just as we did of the somatic processes. Considering first, then, the changes accompanying arterio-serous fluctuations, we find implicated some of the most conspicuous phenomena of mind. At tolerably regular intervals, varying with habit and surroundings, there come to every individual times when the entire arterial system of the cerebrum receives from the vaso-motor centres stronger impulses, which stimulate its walls to assume an increased tone. Immediately the equilibrium between blood and surroundings is lost; for the increased tone, tending to contract the artery, causes an increase of the arterial pressure, while at the same it time tends to decrease the pressure in the peri-vascular spaces, thus doubly operating to overcome the equilibrium. Immediately exosmosis begins; and this continues until equilibrium is re-established. Doubtless a general osmosis continues after this, in fact is always existent; but the ex-osmosis is in excess only till equilibrium is re-established. In the case we are assuming, the contraction occurred in response to a message from a weary brain, and it continues until the aggregate arterial lumen is greatly reduced in size, the entire brain being bathed in the serum of the peri-vascular spaces. Meanwhile, the heart beat continuing unchanged, the pressure must constantly have increased in the cranial cavity, and also, to a lesser degree in the system at large. Under the influence of increased pressure and deficient oxygenation (the corpuscles being separated by a layer of water from the cells), the cortical cells energize less and less, and finally they vibrate so feebly that consciousness plays fitfully and incoherently, and at last altogether disappears. Sleep has supervened. Still further the arteries contract until the minimum supply of blood is entering them; while the tissues are flooded with serum. Gradually the heart lessens in force, and the equilibrium of arterial pressure is kept up at a much lower level. The

vibratory apparatus of the cortical cells has become quiescent, but the matrix of the cell is undergoing rapid repair. Dissolved in the serum are all the nitrogenous constituents which have been partially lost to the cell during its time of energizing, and which are now eagerly seized upon to build up its degenerated tissues. It is really a time of feeding, and the serum is the pabulum of nourishment. During waking hours, this pabulum was never altogether absent, and a certain amount of repair went on concomitantly with destruction; but now the stimulus of the fiery oxygen is far withdrawn, the fibrils of the cell have ceased to vibrate, and the eager cell matrix revels in the abundant food supply. Each cell is a stringed instrument. From without, during waking hours, come the impulses which cause it to vibrate; the oxygen-laden blood fires the matrix and keeps up the vibration. But now, under the changed conditions of sleep, the instrument is unstrung. In vain the impulse, unless it be a very strong one, comes from without; no sound arises from the slackened cords. The fibres are quiescent; the cell matrix feeds and is builded up again. Waking was the time of involution of the material and evolution of mind; sleep now provides for evolution of the debilitated cell. As, when the sluices are opened in irrigation of an unwatered soil, the thirsty earth drinks in the welcome waters; so the hungry cells of the cortex, irrigated by this great flood of serum, draw to themselves the pabulum that their substance craves. At length the hungry cells are nearly satiated; their outlines are again filled out; they are assuming a condition of instability; their potential energy is ready to be turned to account,—to become kinetic. As the cells fill out, the fibres are becoming tense again; they vibrate slightly to trifling impulses from without. The vaso motor impulses slacken a little, and gradually the arterioles dilate, endosmosis accompanying. The absolute arterial supply is increasing. For a time there is almost an equilibrium between evolution and involution in the brain. Then, from within or from without—from heart, or viscera, or perhaps along the auditory apparatus—comes a slightly stronger impulse. The instrument is strung; its cells vibrate quickly in some locality of the cortex; involution of the cell matrix begins; the arteriole responds, slackens, is dilated, and an increased supply of corpuscles, bearing vivifying oxygen, courses through its enlarged lumen. A dream flits before the returning consciousness of the sleeper; he starts and perchance yawns or stretches; the heart gives a stronger beat, dilating still further the relaxed arterioles: a mass of blood has taken the place of the flood of serum, and the *ego* again has come.

Such are the processes of normal sleep. During normal waking hours, however, the vascular system of the brain is only moderately full; at all times many portions of the encephalon are serum-flooded and undergoing repair; only a small tract being at any time very actively energizing. But there may occur abnormal states in which, the vaso controlling centres failing to properly co-ordinate, a general dilatation of the arterioles causes an unusual hyperæmia of the cortex. In a brain so affected, hour after hour and day after day the oxygen-laden corpuscles sweep in floods through the distended arterioles and keep up a ceaseless, though a perverted and inefficient energizing. Irregular and in-coördinate vibrations are going on everywhere resulting in an inchoate meaningless rush of ideas,—a discord comparable to that which would result if the members of an orchestra were to play without a leader, each independently of his fellows. The normal mind has gone, and the individual in whose brain courses that unchecked current of hot blood, is a maniac. He cannot sleep, he cannot rest; his brain cells continue ineffectually to functionate till their last modicum of energy is gone; till the comparatively stable equilibrium of lowest involution consistent with their existence is reached; in popular parlance, till exhaustion is complete.

These illustrations, in the lines of normal and abnormal arterio-serous fluctuations, might be added to indefinitely, but we must content ourselves with these cursory glances, and go on to a brief study of the other methods of fluctuation.

Arterio-venous oscillations are best illustrated by an extreme case, and of course an abnormal one, since all extremes are so; that, namely, of passive congestion. Here while the aggregate amount of blood may be actually increased, there is, incongruous though such a statement seems, a true anæmia. The venous channels are turgid, and they occupy the space to the partial occlusion of the arteries. Only a feeble current flows through the vessels, and instead of a tense, actively vibrating brain, with mental exhilaration, we have a relaxed, atonic condition, deficient oxygenation and correspondingly inefficient energizing; with lassitude and depression of mind amounting, in extreme cases, to hypochondria or melancholia. Here again we may meet with insomnia, but for very different reasons. Here the brain cannot rest because organic evolution is at all times complete, the pabulum being constantly about the cells, and their substance being in its most unstable condition, needing, at any rate at first, only the active presence of the oxygen to set up its kinetic processes. The lack of "tone"

resulting from general cachexia, which usually accompanies this condition, we cannot stop to consider, though it could not be overlooked in an exhaustive analysis of the subject.

This illustration may be considered typical of the results of abnormal arterio-venous fluctuation. Any turgescence of the veins of the brain is a practical withdrawal of so much blood from the efficient circulation, and, according to the degree and the permanence of the condition, it will result in mere hebetude of mind, or in complete mental alienation. The ordinary normal arterio-venous oscillations, have been already briefly noted, and need not be reconsidered here.

The normal action of the inter-arterial fluctuation has also been referred to, as being exemplified more or less in every healthy mental action, and more especially in protracted thought. Abnormalities here result not so much from excesses and deficiencies, which operate in the other cases, as from inefficient coördination between different arterial branches. A case of simple mania may not suffer so greatly from hyperæmia of the encephalon—though more or less arterial turgescence is usually present—as from a failure of the vaso-controlling apparatus to properly manipulate the blood. The ideas of a mind thus ill-managed run on in a rambling, desultory manner, their associations being often far-fetched and illogical; but they are never truly disconnected, though often loosely spoken of as being so. The same rambling flashes occur to every mind during its most coherent working, but the normal volitional energy guides the arterial currents aright, inhibiting the flow in many channels and permitting it only in a few. A consideration of the causes that lead to equable coördination in one brain and to erratic coördination in another, furnishes one of the most fascinating problems of psychology, but one that cannot be entered upon here. We could willingly dwell upon and attempt to explain the emotions; the "currents" of normal thought, setting in slowly and ineffectually to swell at last to a "white heat" of fervor; the far-reaching coördinations of trained thinkers; the erratic scintillations of the poetic fancy; and many another mental process: but the full discussion of these topics can only be undertaken in connection with the combined consideration of the molecular and molar dynamical conditions of the brain. It may be premised here, however, that many a mental process otherwise obscure finds in the explanation of the blood supply a tolerably clear and palpable elucidation.

Of such paramount importance, indeed, is the cerebral circulation in its relations to the human mind, that the entire process of

self-culture might not inaptly be considered simply the gaining of an unconscious inhibitory control over the encephalic arteries. To gain such control should be the constant effort of every one who inherits a brain exhibiting, in any degree, the elements of instability. Let such a person—and who is not therein included?—never forget that, as the abnormal ever shows only an intensification, depression, or in-coördination of the normal; so in the exhilarated condition of mania we see only the extreme projection of such normal states as result in hilarity, fervid thought, joy, anger and the like; while the depression of melancholia is only the abnormal extreme of such normal conditions as apprehension, fear and grief. A paroxysm of anger is a temporary mania; a "fit of the blues," a modified melancholia; and as these sub-normal states may usually be prevented and controlled; so, often, might the truly pathological condition be averted, even in a brain of bad hereditary tendencies, by a proper, systematic, and unyielding self-culture. No brain is so strong or so good in its hereditary tendencies that its possessor may feel himself altogether free from the possibility of mental overthrow; and on the other hand none is so bad but that something can be done toward making it approximate normal stability. Undue indulgences, lack of control, and habitual excesses may cause the vascular supply of the most stable brain to at least seethe and surge with all the turbulent tumultuousness of a storm-tossed sea; while proper habits, constant vigilance and well-studied hygiene may bring many an erratic brain at last to so control its vascular currents that they shall ebb and flow with the smooth placidity of an unruffled tide,—powerful, well nigh resistless in momentum, yet equable, stable and composed. Such control can be acquired not at all directly, but only through the medium of the subjective resultant of the organic processes; that is, through the directive thoughts of consciousness. And these can operate, not upon the circulation immediately, but only mediately, through influence upon the molecular conditions of the encephalic cells. And this thought brings us, here at the close, to the same point which at first we noted,—an appreciation of the mutual dependence of the vascular and cellular forces; of the salient importance of each; and of the utter helplessness or either by itself. It shows us further that the incomprehensible *ego* which is the resultant of these wondrous somatic forces, re-acts efficiently upon the powers that brought it into being. With which thought—really only a corollary of the law of universal reciprocity of forces—we may well leave this aspect of the subject.

[TO BE CONTINUED.]